

# **Report on BlackLight Power Technology: Its Apparent Scientific Basis, State of Development and Suitability for Commercialization by Liebert Corporation**

Prepared under a Consulting Agreement with Liebert Corporation (hereinafter "my client") effective 11/1/00 and submitted in final form on 1/31/01.

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## **Foreword**

I have observed demonstrations of the BlackLight Power (BLP) process and have reached the inescapable conclusion that it is based on extraordinary chemical reactions that seem to release extraordinary amounts of energy. The explanation provided by Randell Mills, M. D., president and chief scientist of BLP is that, in the presence of certain catalysts, atomic hydrogen undergoes a quantum transition to a lower energy state, releasing energy. Mills has published details of his theory in the open scientific literature, but it is wholly unlike anything that neither I, nor any of my colleagues has previously encountered. It is not widely accepted by the scientific community at large.

Although I am personally rather skeptical of Mills explanation, I did observe phenomena, such as plasmas apparently driven by chemical reactions rather than electric fields, that emitted ultraviolet light. I can offer no alternative explanation of my observations.

The BLP scientists who performed these demonstrations were open and honest in their descriptions of the apparatus. For each demonstration of energy output, a control experiment, identical in all respects except that a chemically similar, but non-catalytic substance, was substituted for the catalyst. The control experiments never exhibited any unusual phenomena, including plasmas or other evidence of energy production.

These demonstrations were not designed to generate power in a fashion that could be accurately measured. However, my observations were consistent with the hypothesis that the BLP process does generate energy and does so with an apparent fuel efficiency 10-100 times that of simple combustion of hydrogen gas.

## Preface

BlackLight Power (BLP) claims to have discovered a process in which ordinary atomic hydrogen (H) is converted to lower energy quantum states, called "hydrinos" (Hy, my nomenclature) by contact with a suitable catalyst, resulting in an extraordinary release of energy. Dr. Randell Mills, the founder of BLP, developed the theory underlying this process. It is novel and therefore somewhat controversial and not yet broadly accepted. The theory's existence is important because it guides the development effort. Its acceptance by certain parts of the scientific community, however, does not affect whether or not the BLP process will provide an energy source with which Liebert can successfully develop a product. This product has the potential to be technologically superior to other relatively small-scale electrical energy generation devices, such as fuel cells.

My objective in this Interim Report is to assess the apparent validity of BLP's claims, the current stage of development of this process and to address, insofar as is practical, the engineering issues that would be important to commercialization of this process.

It is my professional opinion that the BLP process represents a chemical conversion of atomic hydrogen unlike any previously reported the archival scientific literature. Furthermore, this process appears to me to result in an energy release that is at least 10 times greater than the combustion of an equivalent amount of hydrogen gas and there is evidence that I find credible that this factor could be closer to 100 times the combustion of hydrogen.

The contents of this report is based on a visit to BLP's Cranbury, NJ laboratory from 1/8/01 to 1/15/01 and on study and analysis of BLP documents provided by Randell Mills of BLP prior to the visit. During the visit, I observed several demonstrations of the process and had lengthy and candid discussions with BLP personnel, ranging from Mill's, BLP's president, to the scientists and engineers working on the development, to the technicians who set up some of the experiments. I believe that I had free and open access to all aspects of the technology covered by the confidentiality agreement between BLP and me (Keith D. Keefer), although I report only those covered by the confidentiality agreement between BLP and my client.

This report is comprised of two sections and a series of Appendices. Section 1 is my assessment, analysis and opinions of BLP's technology at its current state of development in the context of proposed development and marketing plans. I regard this as my client's intellectual property, to be conveyed to BLP only at my client's discretion. Section 2 describes in more detail the observations I made at BLP and data provided to me by BLP. The Appendices contain technical details of the experiments I observed and figures of some of the apparatus and graphs from which the data were derived and were generously provided by BLP. These data and my observations are BLP's intellectual property and Section 2 will be provided to BLP before release to my client, so that BLP may review them for technical accuracy and protection of proprietary information, as provided for in my confidentiality agreement with BLP. This section will also cover the general nature of any BLP redactions, as provided for in my agreement with BLP. Although the technical content is BLP's property, the actual report itself belongs to my client and BLP should not release it to third parties without express consent.

## **Section 1.**

### **Assessment, Analysis and Opinions Regarding the BlackLight Power Process**

#### **Introduction**

This report is based on both my visit to BlackLight Power's (BLP) Cranbury, NJ laboratory and my study of BLP manuscripts submitted for publication in the scientific literature and reports commissioned by BLP from other institutions.

I found the personnel at BLP to be open, candid and enthusiastic about their results. I observed first hand many of the experiments that BLP has reported. The data that I observed were consistent with those I had read prior to my visit and appear to be completely factual. Although I was often accompanied by my host, William Good, V.P. of BLP, I was in no way escorted and was free to observe in the laboratory and to talk with any BLP researchers at any time, sometimes behind closed doors. All of my questions were answered, even when the answer was "We just don't know yet". I was never given the reply "We are not able to discuss that". These areas are discussed under Redactions in Section 2 and do not, in my opinion, have any impact on the commercialization of the technology. I kept two separate notebooks, one the property of BLP, the other notes upon which this report is based. The latter were copied by BLP prior to my departure, but were not censored, although they were discussed with William Good.

In deference to my audience, I will depart from the usual format of a scientific report and present my conclusions first, at the expense of a more coherent narrative. Although you may have simply asked me the time, ultimately you will need to build the watch, hence the detail provided.

#### **Energy Generated by the BLP Process**

It is my opinion, based upon my observations, discussions with BLP personnel and reports generated by BLP and others, that the BLP process is based on an extraordinary chemical reaction that generates an extraordinary amount of energy compared to the combustion of hydrogen gas by oxygen, i.e. a factor of 10 to over 100. I am unable to conceive of any other explanation for the results of BLP's experiments. There are two distinct classes of experiments, one comprised of strictly chemical reactions and the other based on observations of plasma reactors.

I regard chemical evidence as the most concrete and important. Chemical reactions generate chemical products. Methods of characterizing chemical compounds are well established. If no extraordinary chemical products are produced, the claim of extraordinary energy production by BLP's process is almost fatally weakened. (The lack of evidence of products of a nuclear reaction, neutrons, was the most damning to cold fusion, not the calorimetric results.) There is, however, substantial, although not, in my opinion, incontrovertible, evidence for extremely unusual chemical products.

The mere presence of hydrogen itself in these products, as demonstrated by mass spectroscopy (TOF-SIMS, in BLP jargon) provides good evidence of unusual compounds. The X-ray Photoelectron Spectroscopy (XPS) results show clear

differences in the energy of the chemical bonds in the products from those of the reactants. The Nuclear Magnetic Resonance (NMR) results also indicate that hydrogen present in the products is in a very unusual chemical environment. The First Law of Thermodynamics demands that the difference in free energy between the reactants and the products equals the amount of energy released in a reaction. The existence of reaction products allows, in principle, confirmation of adherence to the First Law by thermochemical measurements. As described in Section 2, I observed a Differential Scanning Calorimetric (DSC) experiment, the results of which, by any standard interpretation, showed an enthalpy of reaction in excess of 7 times that of the enthalpy of combustion of hydrogen.<sup>1</sup> As BLP's synthesis techniques become more refined and reproducible, calorimetric results should become even more compelling.

Obviously, it is the energy generated in the plasma reactors that is of most immediate and practical importance. While the plasma reactions are certainly much more dramatic than those conducted in a DSC, they are also more difficult to quantify. Part of this is due to the rather fickle nature of plasmas themselves. The other part is that the catalysts currently used by BLP need to be heated to produce the vapor necessary for reaction with hydrogen and need an incandescent filament for the dissociation of H<sub>2</sub> gas to atomic hydrogen, necessitating the separation of the contribution from the two energy sources. Qualitatively, the presence of catalyst vapor in the presence of hydrogen (compared to a chemically similar, but non-catalytic control substance used as a reference) makes an enormous difference in the amount of light (in the infra-red (IR), visible and ultraviolet (UV)) produced in these reactions. I find it difficult to believe that these plasmas do not release copious amounts of energy compared with that which would have been produced by a more conventional reaction with the same amount of hydrogen. (There is no air in the reactor and almost any other postulated reaction would generate far less energy than the direct combustion of hydrogen). A calculation presented in Section 2, based on the thermal data reported in Appendix B, yields a heat of conversion index of H to H<sub>y</sub> in the plasma reactor 445X (i.e. 445 times that that would result from the combustion of a comparable amount of H<sub>2</sub>). This figure is not regarded as accurate, both in my opinion and that of BLP; an estimate of 70-100X is much more plausible. The discrepancy is probably due to the conversion of H<sub>2</sub> already present in the reactor in the form of metal hydrides.

The observations of the plasma reactors also provide qualitative estimates of the free energy of the reaction, which, as noted above, is the quantity of interest. A rough conversion of qualitative light output to energy can be made. The free energy is the sum of the enthalpy (heat energy) produced by the reaction and the amount of work that can be extracted in forms other than heat. The latter quantity is the product of the potential (e.g. voltage, temperature or pressure) at which the energy is provided and the amount of matter (e.g. electrons or gas molecules) that moves through the potential. The energy of a photon of visible light is about 1 eV and therefore corresponds to an electrical potential of about one volt. The temperature at which a blackbody starts to emit visible light is about 2000°C (c.f. a tungsten incandescent light bulb at ca. 2880K). One eV is roughly the energy of a single chemical bond. Thus, visible light can bleach organic dyes by breaking chemical bonds and few substances are solid at 2000°C. The plasmas in a BLP reactor radiate well into the ultraviolet, photons having energies roughly in the

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<sup>1</sup>. Strictly speaking, calorimetry measures only the enthalpy [heat] of formation and not the free energy, the actual quantity of importance. They differ by the amount of work done by the reaction, but the latter is difficult to measure and is usually small compared to the enthalpy.

range of 10's to 100's of eV. This means that not only do the plasma reactors generate energy, but they do so under conditions corresponding to a large  $\Delta T$  which, according to the Second Law of Thermodynamics, is very favorable to the efficient conversion of that energy to work, electrical or otherwise.

## **Engineering Considerations**

### *Sustainability and Stability of the Plasma Reactions*

The factor that currently limits the duration of a plasma in BLP reactors is the condensation of the relatively non-volatile catalysts in cooler parts of the reactor, particularly the vacuum outlet tube. At this stage, this is primarily an issue of the design and thermal management of the reactor, engineering issues. Until these are resolved, subtler issues such as filament life and reactor vessel corrosion will remain unknown. The development of more volatile catalysts, currently underway by BLP, will mitigate this problem.

The stability of the plasma and its energy output can presumably be controlled by feedback to the filament and electric fields in the reactor. "Presumably" is used because the role of electric fields to generate or sustain the plasma is not yet well understood. (It appears to be larger a chemical process). A small UPS in the system could function long time constant filter may also facilitate the necessary periodic maintenance of the system without disrupting power to the customer.

### *Construction Materials*

The most expensive materials I saw employed in BLP reactors were stainless steel and fused silica (a.k.a. fused quartz, quartz glass) reaction vessels and nickel metal hydrogen gas dissociators. Again, the use of these materials is primarily one of product design and cost. The stainless steel is used because of the high temperature required to generate the vapor pressure of strontium (Sr) metal catalyst at which the BLP process occurs, but it is also the least volatile of the catalysts under consideration. BLP uses 316 stainless, probably because of its superior corrosion resistance and high temperature performance. A commercial reactor could probably use a more generic steel, such as "18-8", of which the 300 series stainless is a more refined subset. Fused silica is obviously more fragile and is more subject to corrosion by the catalyst materials than is stainless steel. It is, however widely used commercially in halogen cycle lamps. The use of the more volatile and less corrosive catalysts currently being studied by BLP should, again mitigate this problem. The nickel dissociators seem not to degrade under present use conditions. No precious metals or radioactive materials were used in any of the reactors I observed.

### *Scale Up*

The plasma reactors use gas phase reactions so their power output should scale with the reactor volume. Depending on the geometry of the reactor (e.g. the diameter to length ratio of a cylindrical design) a potential decrease in the surface to volume ratio of the scaled up reactor would reduce both the cost of construction materials and the difficulty of thermal management. Mills has provided estimates of power densities of  $1W/cm^3$ , which I regard as rather optimistic in the short term.

### *"Open system" Issues*

My questions in this area were readily dismissed as, "We don't know enough, yet". At the current state of the BLP effort, which is still essentially pure research, this response is justified. Technological development is performed as necessary to support their research effort. However, "open system issues present, in my opinion, a significant engineering challenge to the development of any device lacking moving parts. Obviously, for any technology based upon heat engines, this may not be an issue.

By "open system" I mean that BLP's devices, in their current state of development, are not hermetically sealed. This has the greatest impact on gyrotron-based devices. Hermeticity, in my experience at Sandia, requires that components are connected by "fused" joints, e.g. welds, glass or ceramic seals, solder joints or brazes, and is necessary to maintain even a low vacuum without active pumping. No gasket or swage connection will suffice. It is difficult for me to see how hermeticity can be maintained in a system into which gas must be introduced. However, high vacuum pumping systems are highly engineered and are extremely reliable, operating for months or years, with usually only annual oil changes. A hydrogen consumption of less than 100% would require that  $H_2$  be recycled in the system or exhausted by the vacuum system. Examples of other related issues are cooling water, hydrogen generation by electrolysis, etc. These tend to be relatively high maintenance items that are less controllable by a supplier or lessor.

At a BLP process conversion efficiency of 100x the heat of formation of water, the use of metal hydrides as the hydrogen supply becomes plausible and a sealed system, although one probably requiring active pumping within the sealed system, becomes conceivable, as discussed below.

### **Comments on Mills' Theory**

While not of direct engineering importance, Mills' theory does have an impact on the credibility of the BLP process and hence on the credibility of Liebert's commercialization plans. This is by no means a defense of Mill's theory; that he will have to provide for himself. It is just an attempt to put it in the context of other attempts to incorporate Einstein's General Theory of Relativity and gravity into quantum mechanics and some of the general conundrums posed by quantum mechanics itself.

Quantum mechanics has many unexplained and unsettling mysteries, e.g. the Heisenberg Uncertainty Principle, wave particle duality. Resolving some of these requires concepts that generate their own problems. For instance, consider superposition of states. According to this principle, a coin tossed in a dark room can exist in both states, heads and tails but its observed state is only resolved when the lights are turned on. Attempts to incorporate General Relativity lead to "vacuum states" in which electric fields are spontaneously created and then annihilated, which to me hearkens back to the theory of ether. These issues are the subject of popular scientific articles in respected periodicals such as "Scientific American" and "Science News". Attempts at "Grand Unified Theories" and theories of the cosmos result in more bizarre phenomena, such as eleven dimensional "superstrings", "dark matter" (which certainly would encompass Mills' hydrinos) and even antigravity.

I believe that some of the derision accorded Mills by some of his colleagues arises from his style of presentation of his theory and not BLP's experimental results. While very reasonable and affable in person, his writing style is somewhat confrontational. Solid scientific evidence (assuming it is forthcoming) will eventually generate converts.

### **Caveats About Thermochemical Calculations**

There are two. One concerns the normalization of energy to a unit of matter, the other the thermodynamic reference states upon which tabulated values of energy differences are based. At this stage of knowledge, these caveats are more important to understanding the consistency (or apparent lack thereof) of some of the calculated values, rather than the values themselves.

First, the reaction for the enthalpy of oxidization of hydrogen for which values are tabulated is  $\text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O}$ , that is enthalpy per mole of hydrogen gas. BLP typically reports enthalpies of reaction per mole of hydrogen atoms, so they must be compared to  $\frac{1}{2}$  of any quantity referred to moles of hydrogen gas.

Second, only differences in energy between two thermodynamic states can be measured. The reference point for so-called Standard Enthalpies and Free Energies is generally reactants and products at a temperature of 25°C. However, values are often tabulated for two different states of the products. For example, the enthalpy of formation of  $\text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O}$  liquid is 285 kJ/mole, whereas that for the same reaction in which the product is  $\text{H}_2\text{O}$  gas, a different reference state, is 241 kJ/mole. The difference is due to the latent heat of vaporization of water and the difference in the heat capacities of liquid water, water vapor and  $\text{H}_2$  and  $\text{O}_2$  gas.

### **Mass and Energy Balance Calculations**

I am providing some crude mass and energy balance calculations that affect some of the engineering estimates. BLP tends to provide energy balance calculations that are more applicable to their device than to an entire engineered system.

The base assumption for these calculations is an average power output of 1 kW for one year. This gives a total energy output of  $3.14 \times 10^7$  kJ/year. The "unit" of energy I will use is the heat of formation of water vapor from hydrogen and oxygen, 241 kJ/mole of water vapor. At 100% combustion efficiency, this is the energy supplied by  $130 \times 10^3$  moles of  $\text{H}_2$  gas, which has a volume of  $2.92 \times 10^6$  liters or  $103 \times 10^3$  cu ft. This amount of hydrogen is generated by the complete hydrolysis of  $2.34 \times 10^3$  liters of water.

At a baseline of BLP conversion efficiency of 10x the heat of formation of water vapor, this generating capacity requires 0.64 liter of water/ day. Such a system would be "open" as discussed above.

A sealed system using titanium hydride ( $\text{TiH}_2$ ) as a replenishable hydrogen reservoir becomes plausible at conversion efficiencies of 100x. The volume of Titanium (Ti) required to store a year's supply of  $\text{H}_2$  gas would be around 20 liters.

## Section 2.

### Technical Observations of the BLP process

#### Redactions

There are three technical areas that BLP considers sensitive and proprietary and not covered by the current confidentiality agreement with my (Keith D. Keefer) client. I will discuss them, with BLP's permission, only to the level of detail that I believe might have an impact on my client's engineering efforts.

1. Specific catalysts and catalyst systems not yet reported in the literature.

These catalysts tend to be more volatile than those previously reported and their development will only make the engineering of a commercial product easier. Complete peak assignments in the spectra were omitted to preserve confidentiality.

2. Specific operating parameters of BLP reactors.

These obviously do affect engineering. I report an engineering envelope that I devised based on my own judgment and experience that encompasses the BLP process and was agreed to by BLP, but is not based directly on any BLP information, again to provide confidentiality.

- A. Operating temperatures.

The maximum operating temperatures are within the range in which stainless steel could be used, roughly 600°-650° C. The minimum, which depends on item 1 above, could be as low as ambient.

- B. Operating pressures

These range from low vacuum (i. e. less stringent) as defined by the vacuum sustainable, with modest active pumping, with standard Buna-N O-rings. The upper range is 100 psi, a pressure readily achieved by "hardware store" air compressors and contained by standard, non-armored, pressure hose. The suitability of elastomeric materials is subject to item A.

- C. Operating voltages

Less than 600V, the (hardware store) rating of ordinary house wiring.

3. The engineering details of the BLP gyrotron

These primarily affect the scale up and efficiency of the gyrotron. I will report, because it has a bearing on engineering design, with BLP's permission, that the microwave cavity of the test device that I saw was roughly 4 inches in diameter and 4 inches long. The details of the dimensions and design are proprietary to BLP.



## **Observation of Plasma Monitored by Vacuum-Ultraviolet (VUV)-Visible Spectroscopy**

The reactor in these demonstrations was a closed end fused silica tube about 2 inches in diameter. Placed in this tube was a mixture of strontium (Sr) metal catalyst and a proprietary activatable catalyst or a magnesium (Mg) non-catalytic control with the activatable catalyst. Also in the tube was a tungsten filament wrapped around a ceramic tube. This filament both heated the metal catalysts to provide metal vapor and to provide a means of dissociating  $H_2$  gas to atomic H. It also provided the weak (1-10 V/cm) electrical field necessary to initiate a plasma with Sr vapor. A band heater was placed around the tube near the closed end to prevent condensation of metal vapor in this cooler zone. The entire tube, except for the opening, was contained in an insulated box. The open end of the tube was sealed with a Viton O-ring and a Pyrex cap with 5 tubulations: two were electrical feedthroughs for the filament, one for the admission of  $H_2$  gas, one for a vacuum connection and the fifth was connected to the VUV-Visible spectrometer, which used a normal incidence monochromator. (A schematic of the apparatus, without the VUV observation port, is shown in Appendix B., Fig.1)

I observed three demonstrations of this apparatus. In the first a mixture of Sr catalyst and a proprietary catalyst that had a vapor pressure higher than that of Sr, hence heating requirements were dictated solely by the Sr. Initially only a reddish glow from the tungsten filament was observed. After several hours, the apparatus had reached a temperature at which the Sr vapor pressure was high enough for the reaction to occur at a significant rate. Bright white light was observed through the Pyrex cap and the spectrum in the range from VUV to UV, 40-170nm, was recorded by the spectrometer (Appendix A, Fig. 1). The plasma was most intense inside the cap itself, where the electric field from the leads to the filament was highest. The leads themselves glowed at red heat. The second demonstration used Mg metal, a non-catalyst control, with the activatable catalyst. The operating conditions were identical and the same reactor vessel was used. Only the reddish glow from the filament was observed even after several hours of operation and there was no light emitted from the leads. The spectrum recorded is shown in Fig. 2. The salient feature in these spectra is magnitude of the hydrogen Lyman emission line at about 121nm. About 200,000 photons per second were recorded from the reactor containing Sr while only 1,800 were recorded from the reactor when it contained Mg. The latter value is larger than typically measured by BLP and may be due to some activation by the proprietary catalyst referred to above. In the third experiment, Sr and the activatable catalyst were used again, but the transparent Pyrex cap was surrounded by Al foil to raise its temperature and therefore the vapor pressure of Sr in the cap. Two thermocouples were placed on each side of the cap, to provide a rough estimate the of heat flux. The analysis of the thermocouple measurements is described below. Again, a brilliant white light was visible through an observation hole in the Al foil shroud.

### **Heat Flux Measurements of the VUV Reactor**

The thermal power generated in the VUV style reactor described above was estimated from thermocouple measurements. The energy generated by the reactor is calculated from the heat flux and the flow rate of the  $H_2$  fuel.

Appendix B details the measurements and calibration of the heat flux. Fig. 1 shows the placement of the thermocouples (circled numbers). Only readings from thermocouple 9 are used in the power calculation. Unlike some of the other catalysts used in the BLP process, strontium (Sr) requires a small (1-10V/cm) electric field to raise its electron

binding energy to that of atomic H, in accord with Mills' theory. This permits the plasma in an Sr catalyzed reaction to be turned on and off by adjusting the power supplied to the filament, which also provides the electric field. (More detail is provided below.) Figure 2 shows the results of temperature readings of an experiment in which thermal spikes were generated by the adjustment of the filament power, in a reactor configuration the same as the third one described above. Figure 3. is the result of a similarly instrumented reactor with a 300W halogen light bulb as the heat source instead of the Sr catalyzed plasma. The power supplied to the two heaters, filament and band was the same in both cases. Figures 3.1 and 3.2 are expanded scales of the temperature spikes recorded from two different light bulb power settings. Figure 4 is the calibration curve derived from the light bulb, relating the observed temperature rise to the bulb power. Figure 5 is an expanded scale of the thermal spike used for the power estimation. The power observed from the reactor is 163W, a figure arrived at by normalizing the observation time to that used for the calibration curves. A similar figure, 139W, was obtained from the same calibration curve from the temperature readings from the experiment that I observed. Although a molar conversion energy of H to  $H_2$  may be calculated from these data, the figure (445x the combustion of  $H_2$ ) is regarded as exaggerated, by both BLP and I. The most likely reason is that  $H_2$  can be retained in the metal catalysts as hydrides, and so the reaction of  $H_2$  already present in the vessel may have contributed to the observed energy output.

#### **Observation of Plasma Monitored by a Visible Light Spectrometer**

The configuration of this reactor was the same as that described above, except that potassium (K) metal was used as the catalyst. Because K is much more volatile than Sr, the closed end of the reactor vessel protruded from the insulated box. Unlike the previous experiments in which the Sr was placed in proximity to the tungsten filament, the K metal was placed at the closed end of the tube outside the insulated box and was heated with a separately powered heat tape. Again, after an equilibration period, a white light was observed in the apparatus. At my request, the heat tape surrounding the closed end of the tube was removed so that K metal vapor would condense there and not be present in the vicinity of the dissociating filament. In a few minutes, the bright white light disappeared, demonstrating that K metal vapor was essential to the reaction generating the plasma. A control experiment with a non-catalyst was run in the same reactor the next day and showed no unusual emission of light.

#### **Observation of Plasma Generated by Electric Discharge**

In this demonstration, the reactor was a stainless steel vessel heated externally in a furnace. Instead of a filament, a nickel (Ni) mesh was used as the hydrogen dissociator. (See Appendix C for more detailed reaction conditions and a diagram of the apparatus, Fig. 1). The Ni mesh also served as one electrode for the electrical discharge and the stainless steel vessel as the other. A port with a sapphire window allowed observation of the discharge and a fused silica rod was used as a light conduit to couple visible light to the spectrometer. Two experiments were performed, one with Sr metal catalyst, the other with sodium (Na) metal as a control. The reaction conditions used for the control were optimized for discharge from Na using data from A. von Engle, *Ionized Gasses*, American Institute of Physics, p. 196. Unlike the fused silica reactors, the applied electric field was AC rather than DC, so the peak voltages were about 40% higher than those reported. However, electric power input was monitored with true RMS instrumentation.

The electric discharge phenomenon was only recently discovered and the nature of all of the plasma experiments is such that the principal physical observable is the ratio of the power input to the power output. Certain assumptions must be made to extract a measure of the actual energy generated by the reaction. The experimental data are reported in Figs. 2 and 3 of Appendix C. The key result is that with the Sr catalyst, the operating parameters could be tuned such that a plasma was sustained at a voltage of 16.7V RMS (the electrode gap being about 1.75 cm) and an input current of 0.5mA, an input electrical power of 7.2mW. The spectrally integrated visible light output was 0.74 microwatts per cm<sup>2</sup> at the detector face. The maximum measured visible light output from the reactor containing Na control (reference material) was less than 0.1 microwatt at an applied voltage of 327V and an electrical power input of 162W. Thus the ratio of the power required by the Na containing reactor to produce less than one seventh the optical power of the Sr reactor is 22,500. The observable spectral response in this apparatus is limited by the transmission of the windows. The significant contributions in the IR and UV are not measurable and so even a qualitative estimate of the energy generated by the reaction in this apparatus is not possible.

### **Differential Scanning Calorimetry of Hydrino Generating Reactions**

Because of the power input required to sustain a plasma in BLP reactors, direct calorimetric measurements are difficult and somewhat tricky. Calorimetric measurements of chemical reactions, while still tricky, probably provide the most accurate measurement of the enthalpy generated in the BLP process. I observed two such measurements, one on a catalytic system and one on a control. My interpretation of the data is in agreement with that of BLP: the reactions I observed generated an enthalpy of reaction at least a factor of seven larger than the enthalpy of combustion of H<sub>2</sub> gas with oxygen.

The technique that BLP uses, Differential Scanning Calorimetry (DSC), is widely used in Materials Science, but differs from many of the methods more familiar to chemists and engineers. Since the results of these measurements are important and data are presented here, I believe that a brief explanation of the measurement and why it is used by BLP is in order.

Many calorimetric measurements are conducted at near ambient temperatures, where heat transfer occurs primarily by conduction and convection. At higher temperatures, e.g. greater than 250°C, radiant heat transfer dominates and optical properties of the apparatus, such as emissivity and reflectivity must be accounted for. In DSC, a reference material, almost invariably aluminum oxide, is heated in a reference cell identical to that of the sample cell, in close proximity, in the same insulated furnace. Heat output is derived from the difference in temperature between the two cells, hence almost all of the influence of heat transfer cancels out. Although the actual physical observable is temperature, the instrument can be accurately calibrated from the well-known thermal properties of aluminum oxide and from heats of fusion of standard reference materials known well from other measurements. Unlike many other techniques, DSC is not isothermal: the temperature of the furnace is slowly ramped up and down so the temperature of the reaction is also measured and the heat consumed or generated is derived from the integral of the temperature difference, time and the calibration factors. There is a baseline that is a function of temperature that reflects the heat capacity of the cells. Deviations from this baseline are due to heat generated or consumed in the sample, but not in the chemically inert reference material. I should note that the instrument that BLP uses, a SETARM 1000 II, is not an ordinary DSC. Its

insulating blanket is at least 5 times thicker than others I have used and the maximum temperature ramp rate is 0.1 /min compared to 10 /min. The slow ramp rate minimizes distortions due to reaction rates and is dictated in part by the thickness of the thermal insulation, which slows the rate at which an approximately steady-state thermal gradient can be maintained.

I observed two DSC measurements, one, the reaction of potassium hydride (KH) with potassium iodide (KI) and the other a control of magnesium hydride ( $\text{MgH}_2$ ). Potassium hydride is comprised of both a catalyst (K) and the fuel (H). The results are shown in Appendix D., Fig. 1. Downward peaks are endothermic. The ones observed between 350° and 400°C are due to the decomposition of KH and the one at about 660° is due to the melting of KI. The former are broader than the latter because a decomposition reaction is generally slower than melting and the temperature is a function of time. The huge, broad positive (exothermic) peak is ascribed to the formation of hydrido hydrogen and its reaction to form  $\text{KHyl}$ . The enthalpy derived from the integration of this very broad peak is equivalent to 7.0 times the molar heat of formation of  $\text{H}_2\text{O}$  from  $\text{H}_2$  and  $\frac{1}{2} \text{O}_2$ . The control,  $\text{MgH}_2$  shows only two endotherms, one at 350°C from the decomposition of  $\text{MgH}_2$  to Mg metal and  $\text{H}_2$  and one at 650° from the melting of Mg metal (Fig. 2). Fig. 3 shows the reaction of KH alone the results of which I requested from BLP's archives. The observed enthalpies represent lower limits of the molar enthalpy of reaction, since the H to Hy conversion efficiency is not known with great accuracy and the reported number is based upon 100% conversion. The substantial observed enthalpy difference between the reaction of  $\text{KH}+\text{KI}$  and KH alone is not necessarily due the enthalpy of formation of  $\text{KHyl}$  as opposed to the reaction of H to form Hy, since the presence of KI could substantially change the conversion efficiency of H to Hy. Although the exotherms are very broad, and by DSC standards unusually shaped, the two presented here and others I saw in the BLP archives are strikingly similar. For example, there is a change in slope from the baseline at 300°C, a double endotherm between 350° and 400°C, the onset of the exotherm at 400°C (the sharp spikes are noise), the plateau at around 450°, the broad peak at 500° and the long tail out to about 650°. In my experience, these attest to a well-defined and reproducible chemical reaction. The differences in enthalpy arise from the magnitude and breadth of the exotherm, which are the result of the rate and duration of the reaction, variations to be expected in gas phase reactions under non-isothermal conditions.

### Synthesis Reactions

The difference in the enthalpy of formation of the reactants and the products is the most accurate and incontrovertible evidence of the efficacy of energy production. The products of these reactions may, themselves, be commercially valuable.

I observed four synthesis reactions of  $\text{H}_2$  and KCl to form  $\text{KHylCl}$ , catalyzed by K metal. These reactions were conducted in stainless steel vessels under conditions similar to those used in the electrical discharge experiments described above, except the vessels lacked electrical feed-throughs and an observation port. The experimental conditions are reported in the Appendix. Hydrogen uptake in excess of that of the Ni dissociator was monitored by the periodic addition of  $\text{H}_2$  gas to maintain a constant internal pressure.

The most significant analytical results from these products are the Nuclear Magnetic Resonance spectra shown in Figs 1-5. Briefly and crudely, NMR signals arise from nuclei with an odd atomic weight such as a proton ( $^1\text{H}$ ). When a magnetic field is